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(54) **PISTON THERMAL MANAGEMENT IN AN
OPPOSED-PISTON ENGINE**

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14, 2012.

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F16J 1/00 (2006.01)
F01P 1/04 (2006.01)
F02F 3/18 (2006.01)
F01P 3/06 (2006.01)
F02F 3/22 (2006.01)
F02B 75/28 (2006.01)
F02F 3/00 (2006.01)

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CPC .. **F02F 3/16** (2013.01); **F01P 1/04** (2013.01);
F02F 3/18 (2013.01); **F16J 1/00** (2013.01);
F01P 3/06 (2013.01); **F02B 75/282** (2013.01);
F02F 3/22 (2013.01); **F02F 2003/0061**
(2013.01)

(58) **Field of Classification Search**

CPC F02F 3/16; F02F 3/18; F02F 3/20;
F02F 3/22; F02F 3/26; F02F 5/00; F16J
1/00; F16J 1/01; F16J 1/005; F01P 1/04;
F01P 3/06

USPC 123/41.35, 51 B, 193.6; 92/174, 176,
92/186

See application file for complete search history.

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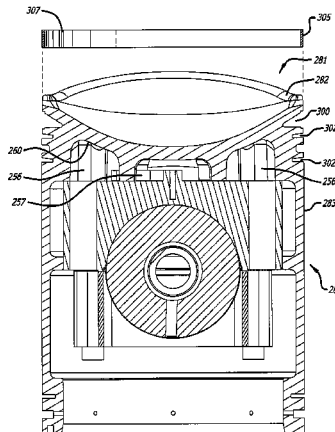
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Julie J. Muyco

(57) **ABSTRACT**

An opposed-piston engine includes pistons, each piston
having an annular cavity in the piston's sidewall and posi-
tioned between its crown and ring grooves to block transfer
of heat from the crown to the piston body.

6 Claims, 9 Drawing Sheets



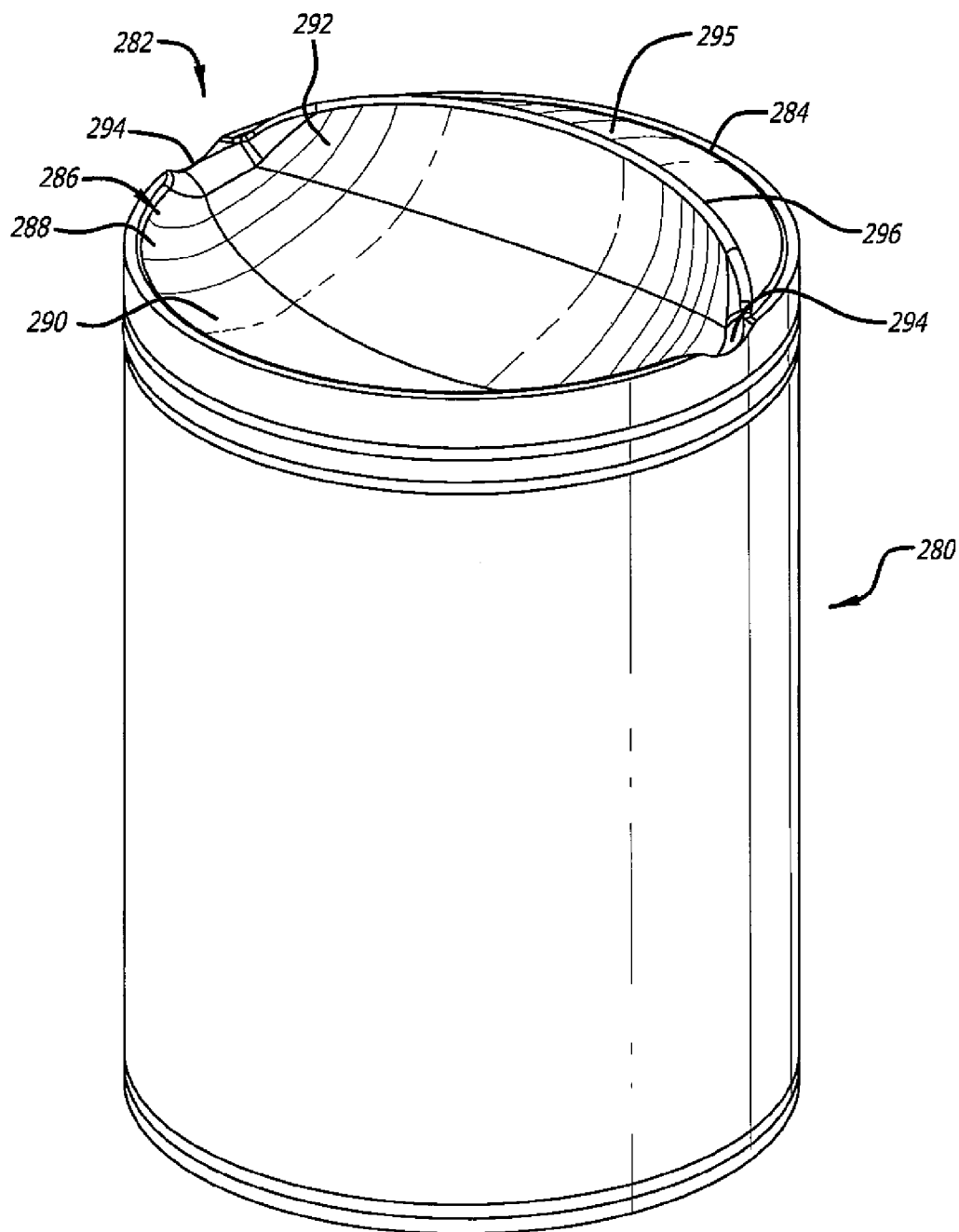


FIG. 1

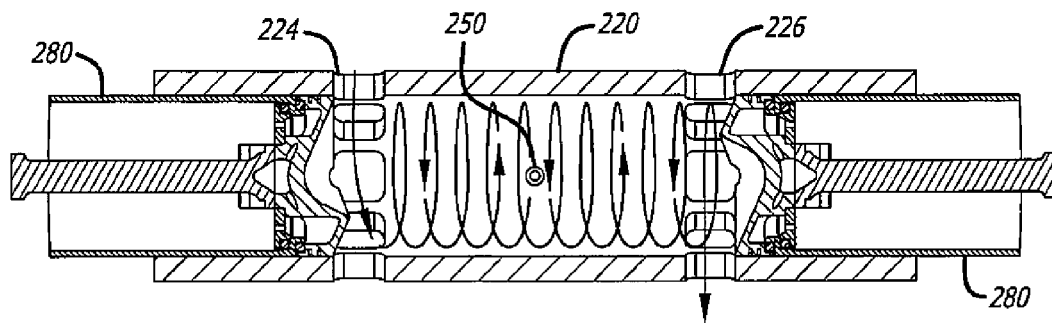


FIG. 2

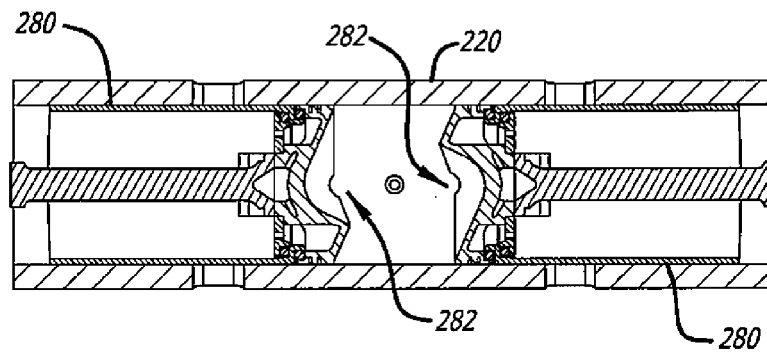


FIG. 3

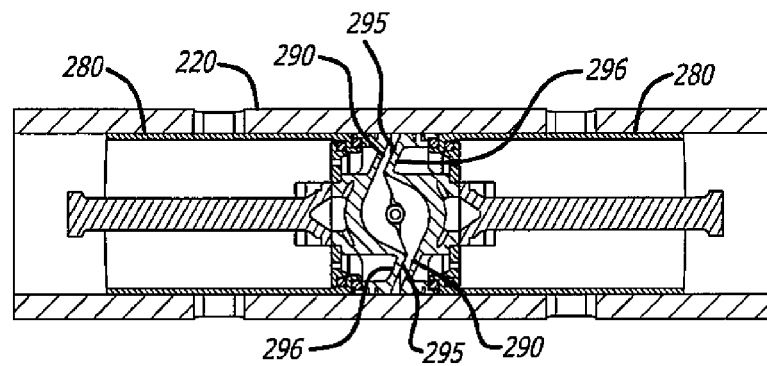


FIG. 4

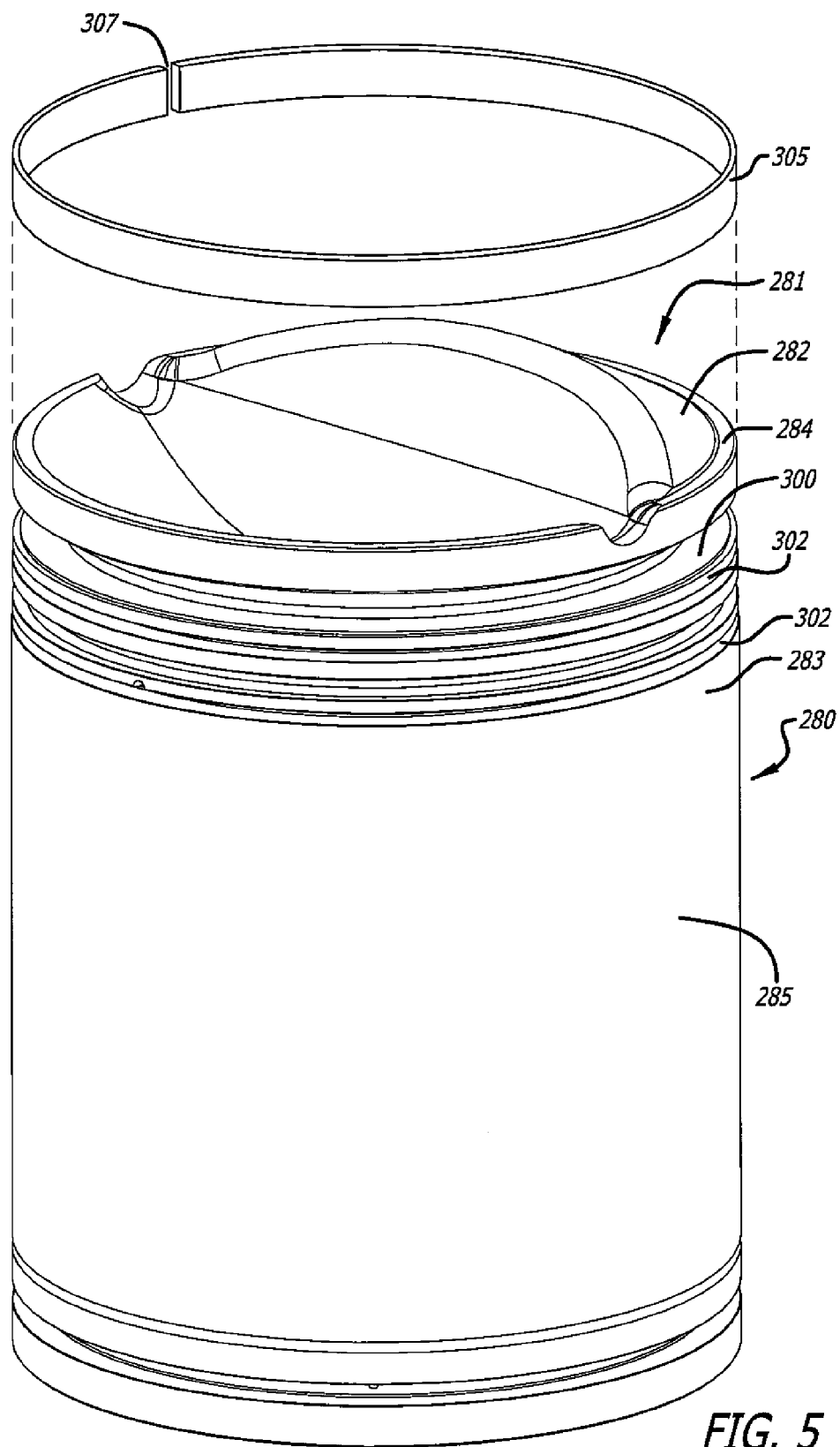


FIG. 5

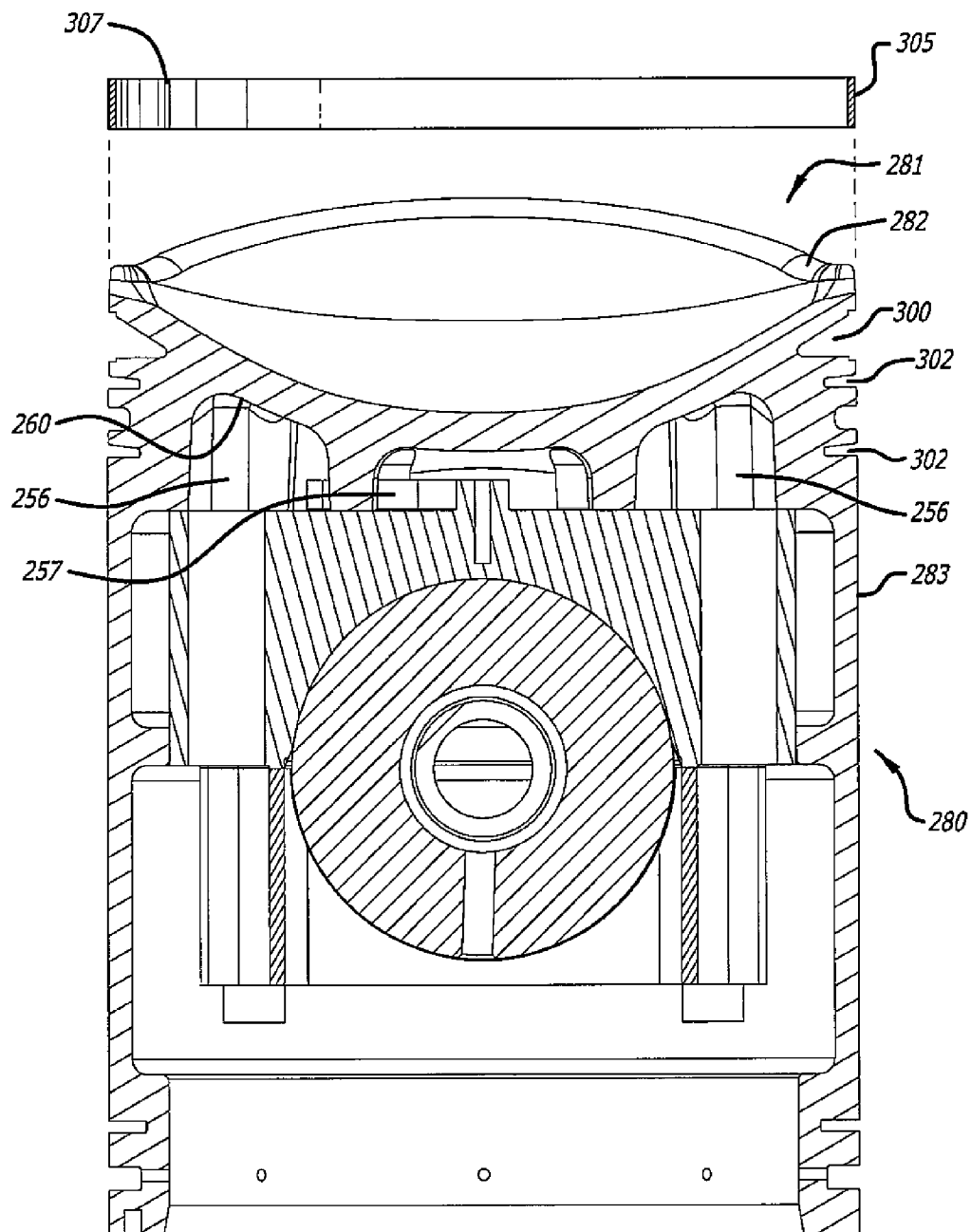


FIG. 6

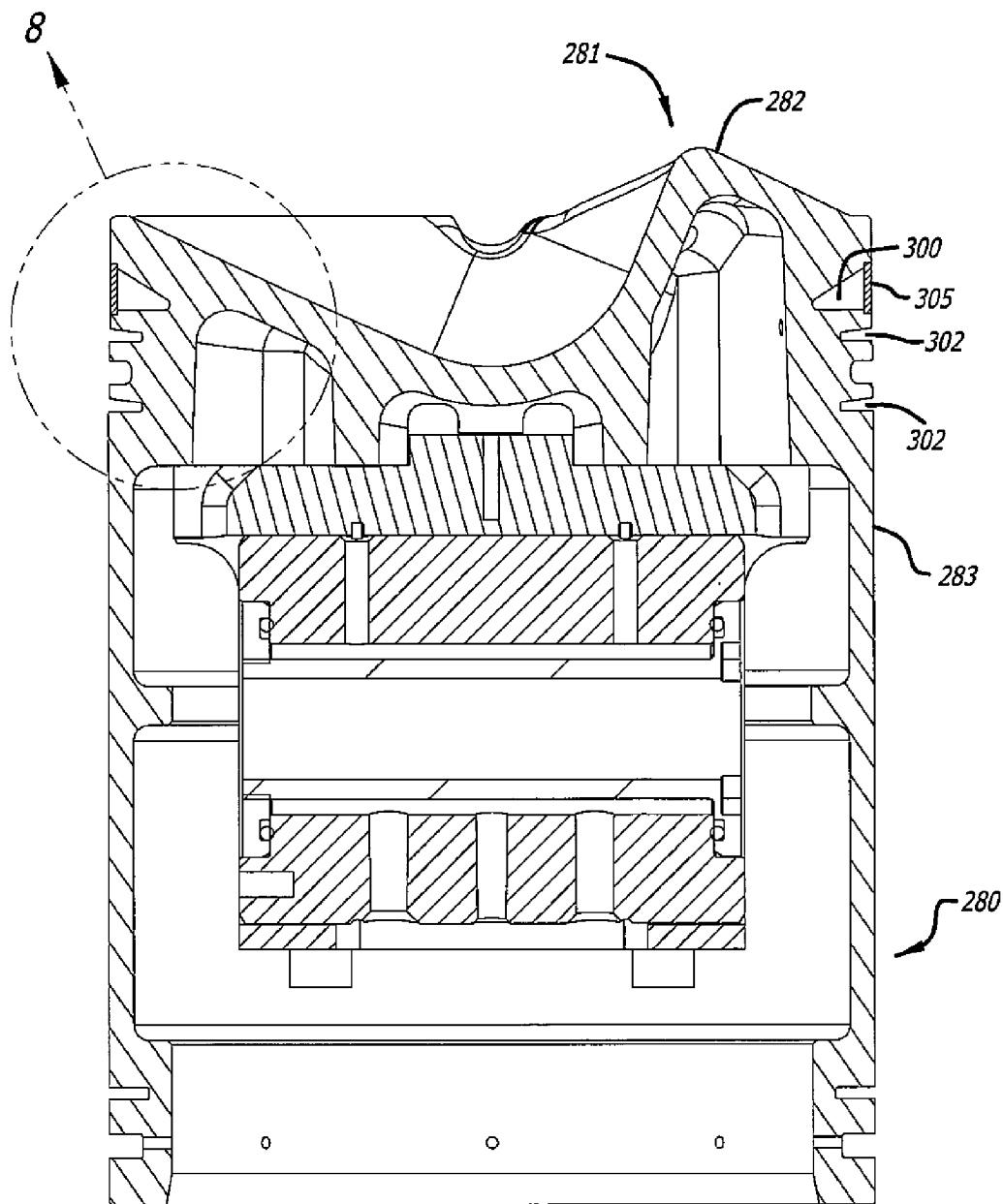


FIG. 7

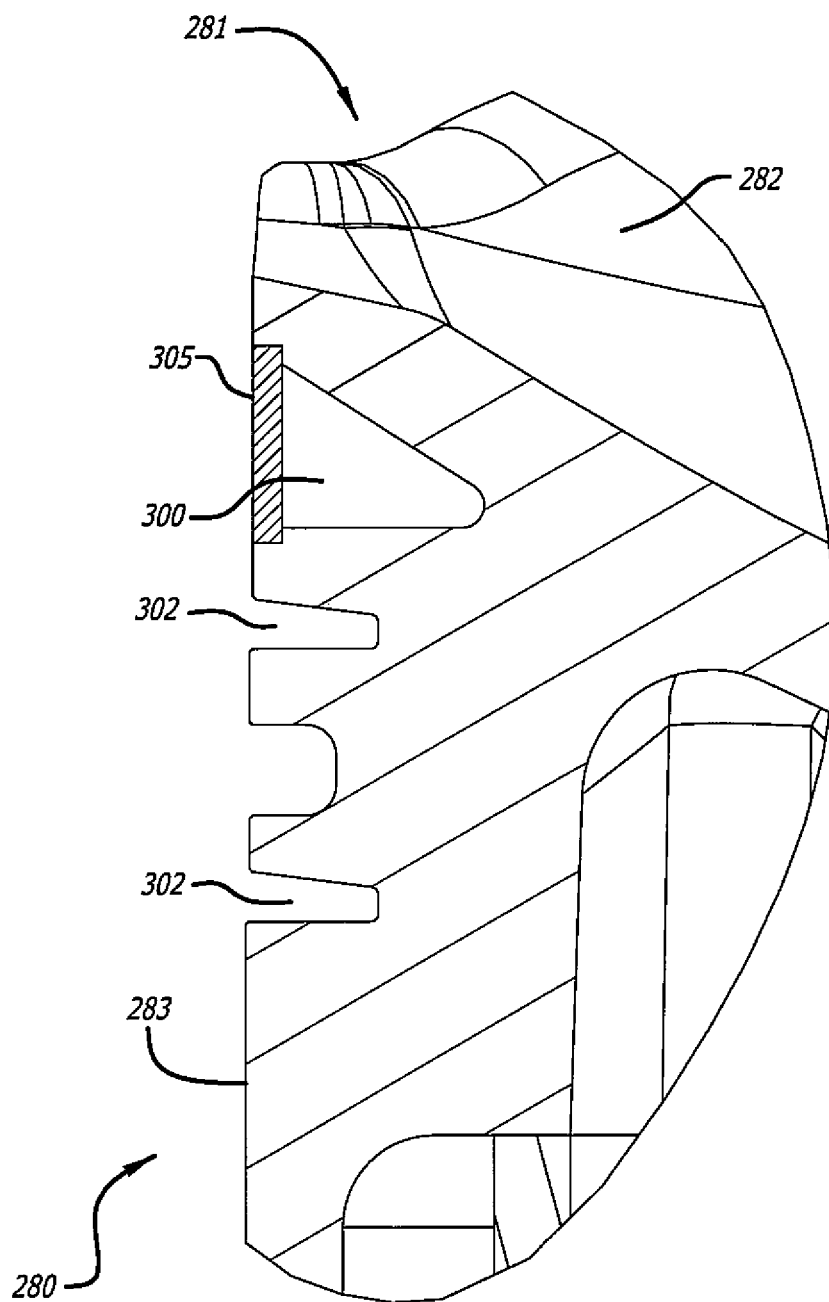


FIG. 8

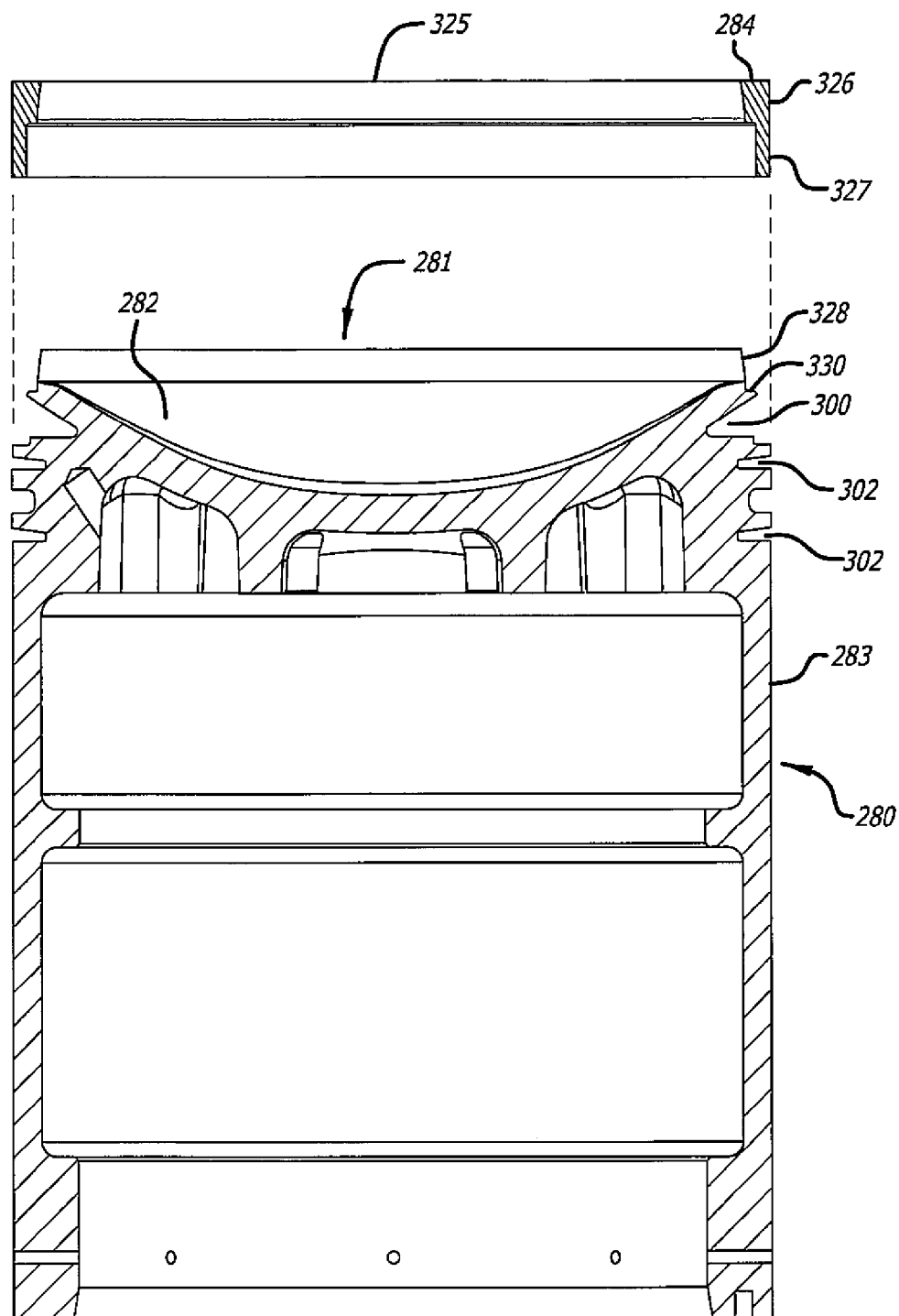
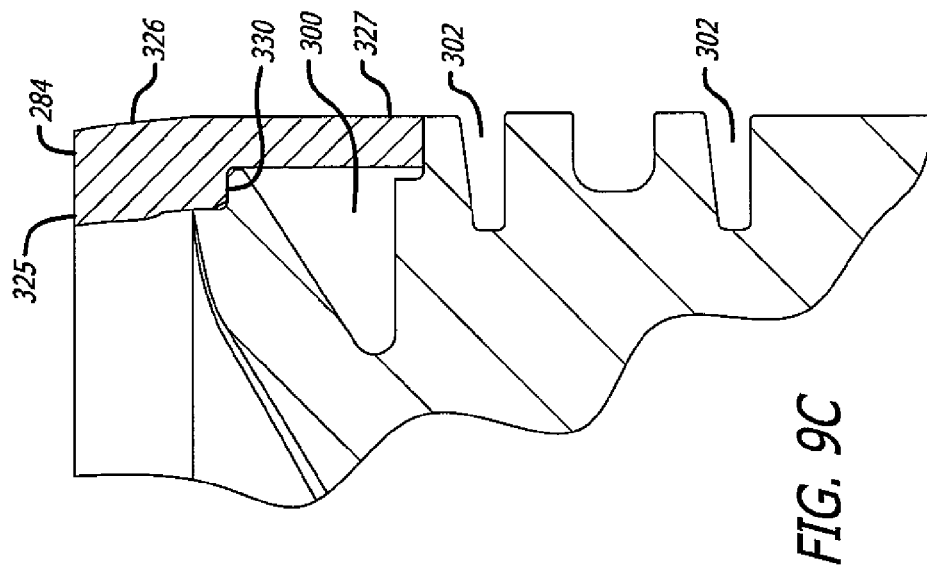
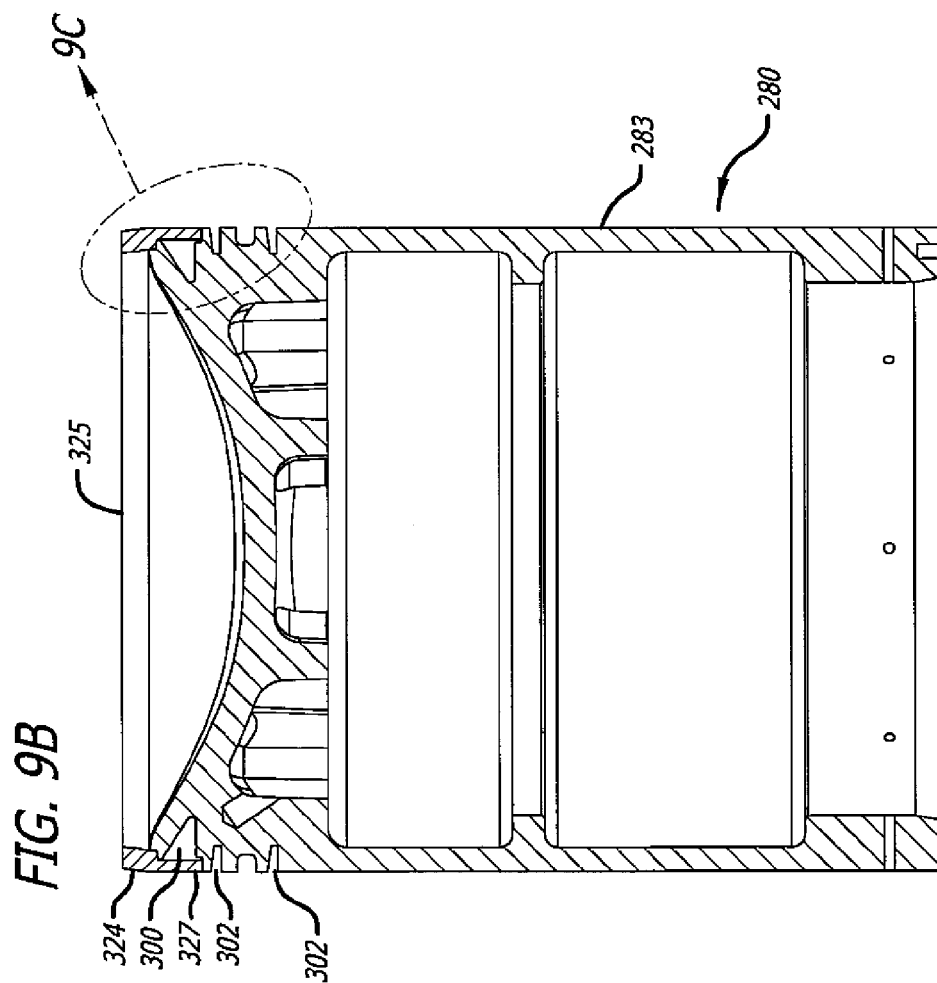


FIG. 9A



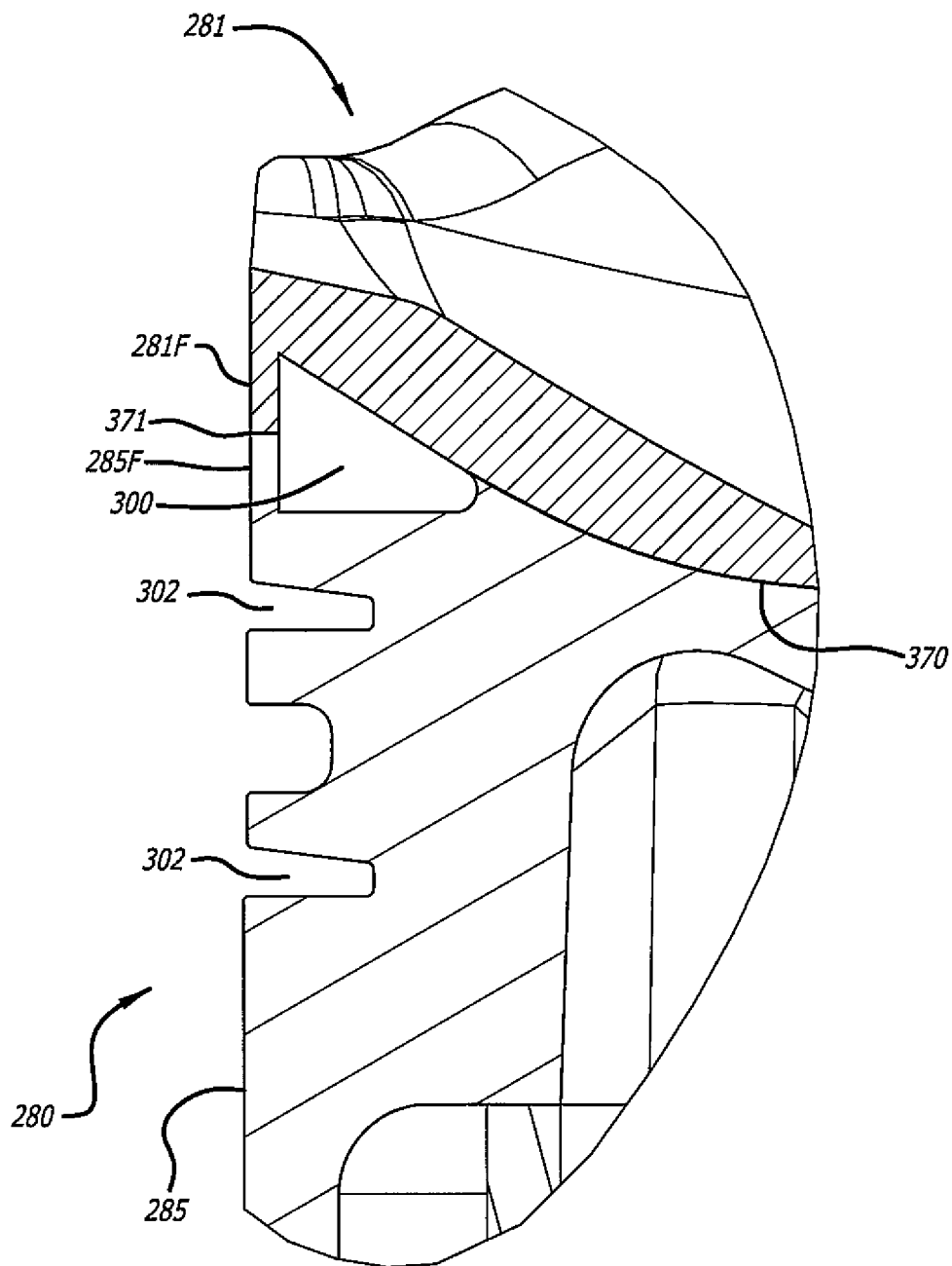


FIG. 10

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PISTON THERMAL MANAGEMENT IN AN OPPOSED-PISTON ENGINE

PRIORITY

This application claims priority to U.S. provisional application for patent 61/646,784, filed May 14, 2012.

A CROSS REFERENCE TO RELATED APPLICATIONS

This application contains subject matter related to that of commonly-owned U.S. patent application Ser. No. 13/066,589, filed Apr. 18, 2011 for "Combustion Chamber Constructions for Opposed-Piston Engines" and commonly-owned U.S. patent application Ser. No. 13/136,955, filed Aug. 15, 2011 for "Piston Constructions for Opposed-Piston Engines".

BACKGROUND

The field is internal combustion engines. Particularly the field is related to constructions for thermal management of pistons. In some aspects, the field includes internal combustion engines in which the end surface of a piston crown is insulated from the ring area of the piston. In some other aspects, the field includes high compression diesel engines, particularly opposed-piston diesel engines.

During operation of an internal combustion engine, combustion of an air/fuel mixture occurs in cylinder space defined by the end surface on the crown of at least one piston reciprocating in the cylinder. For example, in an opposed-piston engine, combustion occurs in the cylinder space defined between the end surfaces on the crowns of two opposed pistons near respective top dead center positions in a cylinder. The heat of air compressed between the end surfaces of the crowns causes fuel injected into the heated air to burn. The cylinder space where fuel combusts is typically referred to as a "combustion chamber".

In order to maximize the conversion of the energy released by combustion into motion, it is desirable to prevent heat from being conducted away from the combustion chamber through the piston. Reduction of heat lost through the piston increases the engine's operating efficiency. Typically, heat transfer through the piston is reduced or blocked by insulating the piston crown from the body of the piston. However, it is also the case that retention of the heat of combustion at the end surface of the piston can cause thermal damage to the piston crown and nearby piston elements.

Piston thermal management is a continuing problem, especially given the ever-increasing loads expected from modern internal combustion engines. In a typical piston, at least four areas are of concern for thermal management: the piston crown, the ring grooves, the piston under-crown, and the piston/wristpin interface. The piston crown can be damaged by oxidation if its temperature rises above the oxidation temperature of the materials of which it is made. Mechanical failure of piston elements can result from thermally-induced material changes. The rings and ring grooves and the lands that border the ring grooves can suffer from carbon build-up caused by oil heated above the coking temperature. As with the ring grooves the under surface of the piston crown can also suffer from oil coking.

A recent study indicates that an opposed-piston engine two-stroke cycle engine exhibits increased thermal efficiency when compared with a conventional six-cylinder

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four-cycle engine. (Herold, R., Wahl, M., Regner, G., Lemke, J. et al., "Thermodynamic Benefits of Opposed-Piston Two-Stroke Engines," SAE Technical Paper 2011-01-2216, 2011, doi:10.4271/2011-01-2216.) The opposed-piston engine achieves thermodynamic benefits by virtue of a combination of three effects: reduced heat transfer due to a more favorable combustion chamber area/volume ratio, increased ratio of specific heats from leaner operating conditions made possible by the two-stroke cycle, and decreased combustion duration achievable at the fixed maximum pressure rise rate arising from the lower energy release density of the two-stroke engine. With two pistons per cylinder, an opposed-piston engine can realize additional thermodynamic benefits with enhanced piston thermal management.

SUMMARY

Enhanced thermal management of the pistons of an opposed-piston engine is realized by provision, in each piston of a pair of opposed pistons, of an annular cavity positioned between the end surface of the piston's crown and the top ring groove of the piston. During engine operation, this cavity reduces the transfer of heat from the piston crown to the piston body, while at the same time reducing or preventing thermal damage to the rings and coking of lubricant in the ring grooves.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevational perspective view of a piston of a pair of pistons in which end surfaces of the pair of pistons are formed to define a combustion chamber construction of an opposed-piston engine.

FIGS. 2-4 are side sectional drawings showing an operational sequence of an opposed-piston engine including a pair of pistons according to FIG. 1.

FIG. 5 is an elevational perspective view of one piston of a pair of pistons of an opposed-piston engine.

FIG. 6 is a side sectional drawing of a first embodiment of the piston of FIG. 5 showing an annular cavity positioned between the end surface of the piston's crown and the top ring groove of the piston.

FIG. 7 is a side sectional drawing of the piston of FIG. 6 when the piston is rotated 90° on its axis.

FIG. 8 is a magnified view of a portion of the piston of FIG. 6.

FIG. 9A is an exploded side sectional drawing of a second embodiment of the piston of FIG. 5 showing a tubular part, or sleeve, that is received on the crown and seats in place around the piston's end surface so as to close the annular cavity. FIG. 9B is a side sectional drawing of the second embodiment of the piston of FIG. 5, with the sleeve seated on the crown. FIG. 9C is a magnified view of a portion of the piston of FIG. 9B.

FIG. 10 is a magnified partial view of a third embodiment of the piston of FIG. 5.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1-4 illustrate a combustion chamber construction defined by complementary end surface structures of opposed pistons disposed in a ported cylinder of an opposed piston engine. The combustion chamber construction is bordered by squish surface areas. Identical generally symmetrical bowls are formed in the end surfaces of the opposed pistons,

and the pistons are rotationally oriented to place complementary curved surfaces of the bowls in opposition in order to maximize the squish surface areas of the squish zone.

The end surface structure of each piston has a periphery surrounding a bowl defining a concave surface. The concave surface includes a first portion curving away from a plane containing the periphery surface toward the interior of the piston and a second portion curving away from the first portion and protruding outwardly in part from the plane. A convex surface opposite the bowl curves away from the periphery and protrudes outwardly from the plane. The convex surface meets the second portion of the concave surface to form a ridge therewith. Preferably, but not necessarily, the bowl has a semi-ellipsoidal shape. The end surface structure is provided on both pistons and the pistons are disposed in the bore of a ported cylinder with their end surfaces oriented to place complementary curved surfaces of the end surface structures in opposition in order to define a combustion chamber. Preferably, but not necessarily, the combustion chamber space defined between these two end surfaces is, or is very close to, an elongated ellipsoidal cylinder, providing a generally symmetrical geometry to reinforce and sustain the tumble motion. This combustion chamber structure adds a tumble to the bulk motion of air in the combustion chamber, thereby increasing turbulence which enhances air/fuel mixing.

The structures of the piston end surfaces that define the combustion chamber are essentially identical to each other; accordingly, the piston **280** shown in FIG. **1** represents both intake and exhaust pistons. The piston **280** has an end surface **282**. A flat, radially-extending area **284** centered on the longitudinal axis of the piston **280** defines a periphery of the end surface **282**. A bowl **286** is formed within the periphery. The bowl **286** has a concave surface **288** with a first portion **290** curving inwardly from a plane containing the flat circumferential area **284**, toward the interior of the piston **280**, and a second portion **292** curving outwardly from the interior of the piston through the plane. The end surface **282** further includes a convex surface **295** within the periphery that curves outwardly from the plane. The convex surface **295** meets the second portion **292** of the concave surface **288** to form a ridge **296** that protrudes outwardly from the end surface **282**. At least one notch **294** extends through the periphery into the bowl **286**; preferably two aligned notches **294** are provided.

Referring now to FIG. 2-4, two pistons **280** having end surfaces shaped as per FIG. **1** are shown at or near respective bottom dead center (BDC) locations within a ported cylinder **220**. The pistons are rotationally oriented in the bore of the cylinder **220** so as to align the end surfaces in complement; that is to say, the concave surface portion **290** of one piston **280** faces the convex surface **295** of the other piston. Charge air is forced through the intake port **224** into the cylinder, as exhaust products flow out of the cylinder through the exhaust port **226**. For purposes of scavenging and air/fuel mixing, the charge air is caused to swirl as it passes through the intake port **224**. As the pistons **280** move from BDC toward top dead center (TDC) locations as per FIG. **3**, the intake and exhaust ports **224** and **226** close and the swirling charge air is increasingly compressed between the end surfaces **282**. As the pistons **280** approach TDC, compressed air flows from the peripheries of the end surfaces into a combustion chamber having a cavity defined between the end surface bowls. At the same time, compressed charge air nearer the longitudinal axis of the cylinder continues to swirl. As the pistons **280** move through their respective TDC locations, the opposing concave-convex surfaces **290**, **295**

mesh with one another to give the combustion chamber cavity an elongated, generally ellipsoidal shape. Opposing pairs of notches **294** (see FIG. **1**) in the end surfaces **282** define injection ports that open into the combustion chamber at opposing pole positions of the ellipsoidal shape.

As per FIG. **5**, the piston end surface **282** is formed in a crown **281** at the upper end of the piston **280**. One or more ring grooves **302** are formed in the sidewall **283** of the body **285** of the piston **280**, underneath the periphery **284** of the end surface **282**. Piston rings (not shown) are seated in the ring grooves when the piston is fully assembled. A circumferential groove, recess, trench, or cavity **300**, formed along a circumference of the piston sidewall **283**, is positioned between the end surface **282** and the top ring groove. The cavity **300** reduces or blocks transfer of heat from the crown through the lower part of the piston, functioning as a thermal resistor between the crown **281** and the ring grooves **302**. A thermally resistant material is disposed in the cavity **300**. Preferably, but not necessarily, the cavity **300** contains a material with low thermal conductivity. Examples of a low thermal conductivity material include air, ceramics, and/or graphite. Preferably, the cavity **300** is closed to form an annular chamber. For example, the cavity **300** can be closed by a thin, flat encircling strip, or band, **305** that is seated in the mouth of the cavity and fixed to the piston structure. Closing the cavity **300** and/or filing the cavity **300** with ceramic, graphite, or other equivalent material adds structural integrity to the piston. The cavity **300** provides a thermal resistance between the crown **281** and the ring grooves **302** that reduces the transfer of heat into the piston, thereby increasing the conversion of the combustion energy into motion.

The thermal resistance of the cavity will cause the crown **281** to become hotter, thereby increasing the possibility of oxidation. This can be handled in several ways. One is to manufacture the crown out of a material with a higher oxidizing temperature such as a stainless steel or nickel alloy. The other is to use standard piston materials and apply a surface treatment which increases the surface oxidation temperature of the material. Material properties also degrade with temperature. If standard piston materials are used, the piston can be designed with low enough stress to still satisfy fatigue limits.

FIGS. 6-8 illustrate a first embodiment of the piston of FIG. **5**. The annular cavity **300** is positioned between the end surface of the piston's crown **281** and the top ring groove **302** of the piston. Preferably, but not necessarily, the cavity has the shape of a wedge in cross section, with a wide mouth that opens through the piston sidewall and tapers to an inner notch. Preferably, but not necessarily, the sidewall **283** and crown **281** are formed as a single unitary piece by forging, casting and/or machining. Alternately, the crown and piston body can be formed as separate pieces that are joined by standard means such as welding, brazing, or threaded elements. If the cavity **300** is closed with the band **305**, the band is preferably made from a material that is thermally compatible with the material of the piston structure to which it is mounted. For example, materials with equal, or substantially equal, coefficients of thermal expansion, are said to be "thermally compatible." Presuming the use of standard materials for the piston and the band, the band **305** can be seated in the mouth of the cavity **300** and welded in place. If the crown and piston body are formed as a unitary piece, the band **305** can be fabricated with a gap **307** (best seen in FIG. **5**), thereby allowing it to be expanded slightly so as to fit around the crown and moved downwardly therealong until seated in the mouth of the cavity **300**. Once the band

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is seated, the gap 307 can be closed by the same process by which the band is welded to the piston body. Once the band 305 is seated and fixed in place by welding or an equivalent process, the two parts 300 and 305 cooperate to form a chamber that is substantially airtight. The chamber can be filled with one or more materials having low thermal conductivity. Alternatively, air can be drawn from the cavity during the welding process such that the chamber contains a near-vacuum, that is to say, an annular space having a pressure less than atmospheric pressure at sea level.

FIGS. 9A-9C illustrate a second embodiment of the piston of FIG. 5. The annular cavity 300 is positioned between the end surface of the piston's crown 281 and the top ring groove 302 of the piston. Preferably, but not necessarily, the cavity has the shape of a wedge in cross section, with a wide mouth that opens through the piston sidewall and tapers to an inner notch. Preferably, but not necessarily, the sidewall 283 and crown 281 are formed as a single unitary piece by forging, casting, and/or machining. Alternately, the crown and piston body can be formed as separate pieces that are joined by standard means such as welding, brazing, or threaded elements. The cavity 300 is closed with a sleeve 325 having an upper flange 326 that extends in a radial direction and a lower flange 327 that extends downwardly in an axial direction. The sleeve 325 is assembled to an outer circumferential surface 328 the crown 281, with the upper flange 326 held against a peripheral shoulder 330 and the lower flange 327 seated in and covering the mouth of the cavity 300. As per FIGS. 9A-9C, the upper flange 326 of the sleeve 325 constitutes the periphery 284 of the piston's end surface. The sleeve 325 is preferably made from a material that is thermally compatible with the material of the piston structure to which it is mounted. Presuming the use of standard materials for the piston and the sleeve, the sleeve 325 can be seated on the crown, with the lower flange seated in the mouth of the cavity 300, and fixed in place by welding or an equivalent process. Once the sleeve 325 is seated and fixed in place, with the seam between the lower flange 327 and the mouth of the cavity 300 closed by welding or an equivalent process, the two parts 300 and 327 form a chamber that is substantially airtight. The chamber can be filled with one or more materials having low thermal conductivity. Alternatively, air can be drawn from the cavity during the welding process such that the chamber contains a near-vacuum, that is to say, an annular space having a pressure less than atmospheric pressure at sea level.

FIG. 10 illustrates a third embodiment of the piston of FIG. 5. In this embodiment, the crown 281 and piston body 285 are formed separately, with oppositely-directed, axially-extending flanges 281f and 285f. The crown 281 and piston body 285 are brought together, with the pair of flanges 281f, 285f in alignment, while being welded along weld lines 370 and 371. The cavity 300 thereby formed includes space on the insides of the flanges 281f, 285f. If an electron beam welding process a near-vacuum can be created in the resulting chamber. Two useful mass production methods include inertia welding and laser welding, either of which can be used to join the crown and body pieces.

In some aspects, provision can be made to cool the interior of each piston by means of liquid coolant that circulates into the piston, across the backside of the crown, and out the bottom of the piston body. For example, with reference to FIG. 6, liquid coolant (lubricating oil, for example) flows into an annular gallery 256. The liquid coolant strikes the interior surface of the annular gallery at its highest point 260, thereby cooling that portion of the crown by impingement, and flows from there throughout the

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annular gallery 256. From the annular gallery 256, the liquid coolant flows into and through a central gallery 257. Liquid coolant flowing throughout the annular gallery 256 washes and cools an annular portion of the piston sidewall that includes ring grooves 302. Liquid coolant flowing through the central gallery 257 continuously irrigates an interior portion of the crown undersurface. See related application Ser. No. 13/066,589 in this regard.

Although a piston having a cavity to block transfer of heat from the crown to the lower part of the piston has been described with reference to presently preferred embodiments, it should be understood that various modifications can be made without departing from the spirit of the described principles. For example, the piston can have a bowl of various other shapes than as described and illustrated herein. Accordingly, the principles are limited only by the following claims.

The invention claimed is:

1. An internal combustion engine including at least one cylinder with longitudinally-separated exhaust and intake ports and a pair of pistons disposed in opposition to one another in a bore of the cylinder, each piston including a piston body with a crown at one end, an end surface on the crown, in which an end surface of a first piston has a bowl that cooperates with the end surface of an opposing piston to define a combustion chamber, at least one ring groove in the piston sidewall near the crown, an annular thermally-resistant cavity formed in the piston sidewall along a circumference of the piston body and positioned between the end surface and the at least one ring groove, and one of a band, a flange, and a pair of opposing flanges covering the cavity to form a chamber that contains a near-vacuum.

2. The piston of claim 1, wherein the pair of opposing flanges comprises an upper flange that extends in a radial direction of the piston and a lower flange that extends downwardly in an axial direction of the piston, further wherein:

a sleeve comprises the upper flange and lower flange, and the sleeve is seated on an outer circumferential surface of the crown with the upper flange held against a shoulder of the crown and the lower flange covering the cavity.

3. The piston of claim 1, further including one or more cooling galleries within the piston body under the crown.

4. A piston for a two-stroke internal combustion engine, comprising:

a piston body with a crown at one end;

an end surface formed on the crown;

the end surface including an elongated bowl that cooperates with an opposing piston end surface to define a combustion chamber;

at least one ring groove in the piston sidewall near the crown;

an annular thermally-resistant cavity formed in the piston sidewall, extending along a circumference of the piston body, and positioned between the end surface and the at least one ring groove; and,

one of a band, a flange, and a pair of opposing flanges covering the cavity to form a chamber that contains a near-vacuum.

5. The piston of claim 4, wherein the pair of opposing flanges comprises an upper flange that extends in a radial direction of the piston and a lower flange that extends downwardly in an axial direction of the piston, further wherein:

a sleeve comprises the upper flange and lower flange, and

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the sleeve is seated on an outer circumferential surface of the crown with the upper flange held against a shoulder of the crown and the lower flange covering the cavity.

6. The piston of claim 4, further including one or more cooling galleries within the piston body under the crown. 5

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